Mon. Not. R. astr. Soc. (1981) **195**, 805–810

The eccentric, asynchronously rotating, close binary 55 Ursae Majoris

C. Lloyd *Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex BN27 1RP*

Received 1980 October 8; in original form 1980 August 15

Summary. A new orbital solution is derived for the spectroscopic binary 55 UMa. The system is unusual in possessing the shortest known period (2.55385 day) for an orbital eccentricity of 0.43. The rotational velocities of the two components are approximately 2 and 5 times the synchronous rotational velocity and this also distinguishes it from other short-period main-sequence binaries. Both components are main-sequence stars with spectral types in the range A5–A9. The composite broadband colours indicate a slight ultraviolet excess for the spectral type and suggest that one component may be metal weak. It is likely that the system will show apsidal motion and a small (perhaps 0.02 mag) ellipsoidal variability.

1 Introduction

Close binaries with periods less than about four days have almost circular orbits and their components rotate synchronously with their binary motion (Plavec 1970). Even X-ray binary stars, in which a relatively recent explosive event may have occurred, resulting in eccentric orbits and desynchronized rotation (Wheeler, McKee & Lecar 1974), have rapidly circularized their orbits and resynchronized. The viscous forces which circularize and synchronize these binaries evidently act quickly in the early-type supergiants which are primaries of the best studied X-ray binaries. Also dwarf novae which undergo explosive events usually show circular orbits. For late-type stars with extended envelopes convective viscosity is sufficient to circularize and synchronize the orbits relatively quickly (Plavec 1970). For early-type stars with radiative envelopes the radiative viscosity is very small and very inefficient at synchronizing the rotation. In supergiants macro- and micro-turbulence might increase the viscosity, but in main-sequence stars this will not be the case. Early-type main-sequence stars are precisely those which are observed to rotate synchronously with circular orbits in short period binary systems. Press, Wiita & Smarr (1975) have suggested that a large viscosity can result from fully developed turbulence driven by a fluid shear caused by rotation through a tidal bulge. Under these circumstances the time-scales for synchronization and circularization of a mid-A-type binary star of period $P \sim 2.5$ day and eccentricity $e \sim 0.4$ are

$$\tau_{\text{synch}} \sim 6 \times 10^4\,\text{yr}$$

$$\tau_{\text{circ}} \sim 5 \times 10^6\,\text{yr}$$

which are astronomically short. Although the mean rotational velocities of close binary components are substantially lower than those of single stars of similar spectral type, synchronization and circularization are not invariant rules for close binary stars e.g. CD Tau (Mallama 1978) which with an orbital period of 3.4 day rotates at 3.4 times synchronous velocity.

This paper describes the close binary 55 UMa in which both components exceed the synchronous velocity, and the orbital eccentricity is the largest among short period binaries, with the exceptions of the binary pulsar ($P = 0.3230$ day, $e = 0.62$, Hulse & Taylor 1975), the dwarf nova RX And ($P = 0.2117$ day, $e = 0.4$, Kraft 1962), and the nova GK Per ($P = 1.9042$ day, $e = 0.39$, Kraft 1964; A. Bianchini, F. Sabbadin & E. Hamzaoglu 1980, private communication). 55 Ursae Majoris (HR 4380) is a bright ($V = 4.75$) spectroscopic binary whose spectrum contains two components of similar spectral type which are never completely resolved. One has considerably broader lines than the other. The last published spectroscopic investigation of the system was by Henroteau (1919) who determined a preliminary set of orbital elements. Batten, Fletcher & Mann (1978) in the Seventh Catalogue of Spectroscopic Binary Orbits raised doubt over the period of 2.5 day found by Henroteau and commented that a large number of plates of the system had been collected by Dr R. M. Petrie. These are the plates used in this work.

2 Observations and reductions

The spectra were obtained at the Dominion Astrophysical Observatory between 1954 and 1964 with the IIL and IIM spectrographs giving reciprocal dispersion at Hγ of ~ 11 and 15 Å mm^{-1} respectively. Intercomponent blending is severe and careful attention was paid to selecting stellar lines clear of adjacent lines from the other component at large velocity separations. About 20 suitable lines were found and a small number of additional lines were included for plates around zero velocity separation.

Although the two components are never completely resolved, a narrow core, due principally to the sharp-lined component, is visible throughout the cycle. The broad component acts as a variable background and is bound to distort the profile of the sharp component to

Table 1. Velocities of sharp-lined component used in orbital solution.

JULIAN DATE	VELOCITY	RESIDUAL(O-C)
	KM/S	
2434831.769	-49.4	-1.2
4852.745	-4.3	-1.0
4867.755	-23.4	6.5
4887.779	-66.6	-5.6
5126.998	63.8	-11.4
2435127.031	59.1	-7.4
5181.797	-37.6	-1.1
5181.842	-39.6	-6.8
5202.764	3.5	-6.3
5202.785	3.7	-8.2
2435207.840	3.5	-3.3
5216.788	-70.9	-0.3
5216.815	-65.8	7.1
5229.679	-91.0	-15.3
5925.756	39.6	3.9
2435937.742	-33.1	2.9
5978.757	-10.8	12.7
5986.705	-6.6	-8.0
6266.867	-50.8	9.5
6273.837	11.2	3.3
2436273.847	9.0	6.4
6278.844	55.1	-1.8
6293.742	71.7	9.3
6294.784	-71.0	0.1
6294.797	-74.2	-3.8
2436322.726	-70.9	4.8
6329.713	90.8	7.0
6343.733	-36.4	5.2
6650.758	4.4	-1.9
6693.701	-27.5	6.9
2436695.773	-69.4	-0.2
6987.915	4.4	-6.5
6994.953	-45.3	-2.9
7014.783	-87.4	-12.0
7303.048	0.1	-2.3
2437407.767	-5.8	-2.4
7712.937	-6.5	7.1
7722.818	-36.7	4.3
7736.781	63.2	-12.3
7740.814	-22.6	8.9
7740.838	-31.4	-1.8

some extent, particularly at small and intermediate separations. This may lead to some distortion of the radial velocity curve (Petrie, Andrews & Scarfe 1967; Tatum 1968). The oscilloscope measuring-device was always set on the narrow core; no attempt was made to correct for the blending in an *ad hoc* way. On the occasions when the broad component could be measured some visual smoothing of the profile was necessary. On the higher dispersion plates 15 to 20 stellar lines generally were measured, except near maximum velocity separation, when only five to ten isolated lines could be found.

Reductions to velocities were made via the standard Hartmann curves used at the DAO (Batten, private communication) and the RMS error of the mean velocity from a single plate is typically 5–10 km s^{-1}. On the lower dispersion plates the weak metallic lines were very noisy and only Mg II 4481 was measured. Velocities were determined from 43 higher and 60 lower dispersion plates. Velocities from the higher dispersion plates are given in Table 1.

3 The period and orbital elements

The velocities of the sharp-lined component were subjected to a Fourier transform periodogram analysis which, following the precepts of Gray & Desikachary (1973), allows the identification of spurious periods introduced by the data spacing. The periodogram shows a single series of spikes due to a period of 2.5538 day. In a phase diagram plotted with this period, the lower dispersion velocities show a systematically lower velocity–amplitude, as would be

Table 2. Orbital elements for the sharp-lined component.

$V = -4.6 \pm 1.2$ km s^{-1}
$K = 80.4 \pm 2.0$ km s^{-1}
$e = 0.43 \pm 0.03$
$\Omega = 74\overset{\circ}{.}3 \pm 3\overset{\circ}{.}0$
$T = 2434830.88 \pm 0.02$
$P = 2.55385 \pm 0.00002$ day
$a \sin i = 2.54 \times 10^6$ km
$f(m) = 0.102 M_\odot$
$i \sim 35°$ (see Section 7)
Mass ratio ~ 0.9 (see Section 4)

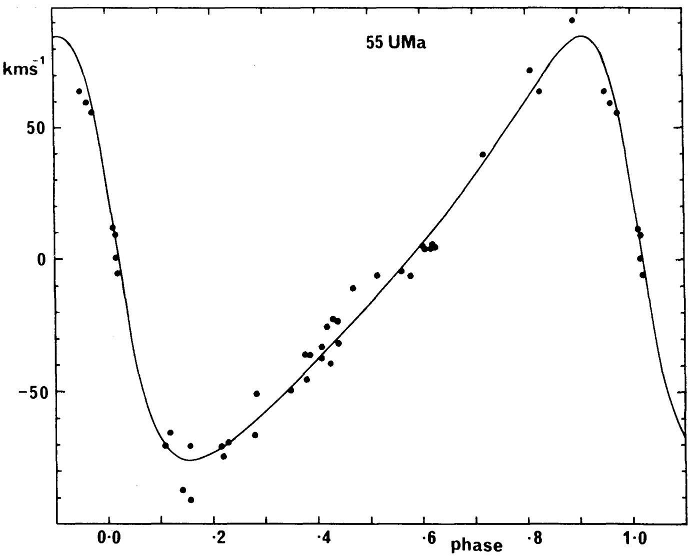

Figure 1. The radial velocity curve for the sharp-lined component of 55 UMa. The velocities were determined from the higher dispersion plates, two of which gave residuals $> 3\sigma$ and were rejected from the orbital solution. Phase is from periastron passage.

expected since they are more affected by blending. Therefore only the velocities from the higher dispersion plates were used to determine the orbital elements and to refine the period. The elements are given in Table 2 and the orbital solution shown in Fig. 1. The most significant feature of the system is the eccentricity $e = 0.43 \pm 0.03$. The RMS residual from the orbital solution is 6.6 $\mathrm{km\,s^{-1}}$, and this agrees well with individual plate errors.

In a further effort to reduce possible errors introduced by line blending, the period finding and orbital element routines were run using the data from large velocity separations, when the effects of blending should be least. The results show no significant differences from the complete data set.

4 The mass ratio

Insufficient broad lined velocities were determined to permit a two-component orbital solution. However, although these velocities show considerable scatter they are consistent with a mass ratio of ~ 0.9 in favour of the broad-lined component being the more massive. Obviously there is considerable uncertainty in this.

5 The spectral types

Henroteau (1919) noted that the spectral type changed throughout the cycle, from A0 with only a few broad lines, to late A or early F when the lines were much sharper, but this is probably explained by the blending of two similar spectra rather than by any physical change. At large velocity-separations the lines of one star are diluted by the continuum of the other and the metal lines in particular are considerably weakened.

Two plates of good quality from phase 0.96 were scanned with a PDS microdensitometer and summed. From a plot of this summation, approximate equivalent widths of several lines in both components were measured. The ratios involving Fe II 4233, Fe I 4063, Ca I 4226, Ti II 4443, Ti II 4468, Sr II 4215, Sc II 4246 and Si II 4128-30 are consistent with both stars having spectral types in the range A5 to A9, although the Si II doublet is very weak. The Ca II *K* line suggests about A6 at single line phase. In early A type metallic lined stars the Sr II 4215: Sc II 4246 ratio is often large (Conti 1970) but although Sc II 4246 is weak the observed ratio suggests that both components are normal. As the Balmer lines have considerable wings both components are unevolved.

In view of the weakness of the lines involved and because the relative contributions of the two continua were not considered, the spectral types found must not be considered as definitive.

6 Photometry

The broadband colours of 55 UMa given in Table 3 are slightly 'blue' for mid to late A stars. Assuming that one component is of spectral type A6, the colour of the other approaches

Table 3. Broadband photometry of 55 UMa.

V	*B–V*	*U–B*	Reference
4.75	0.09	0.04	Eggen (1963)
4.79	0.12	0.03	Iriarte *et al.* (1965)
–	0.16	0.11	A6V; Johnson (1966)
–	0.09	0.04	A2V; Osawa (1959)

that of a B9 to A0 star for reasonable values of the magnitude difference between the stars. This conflicts with the absolute magnitude derived from a distance modulus of ~ 3.4 ± 0.6 mag (Jenkins 1952; Eggen 1963). Also the presence of an early A-type star is ruled out by the spectroscopic part of this investigation. Thus in the two-colour diagram, at least one component of 55 UMa appears to have an ultraviolet excess; indeed its colours are typical of the so-called λ Bootis group of metal-weak stars (Sargent 1965; Baschek & Searle 1969).

7 Discussion

The most striking feature of this binary is the combination of short period and high eccentricity. Two eclipsing binaries which are probably quite similar to 55 UMa are RU Mon (Batten *et al.* 1978) and FT Ori (Cristaldi 1970) of which the latter is the best observed. However, the period of 55 UMa is somewhat shorter and the eccentricity more extreme. This immediately raises the question of whether the observed eccentricity is real. Line blending may distort the radial velocity curve but as described in Section 3, the orbital elements were not unduly altered when the velocities thought to be most affected by blending were removed from the solution. In many short-period systems apsidal motion has been observed. To test for this the data were divided into three groups and the orbital elements routine run with each. None of the results were significantly different from those in Table 2. Some recent image-tube spectra obtained at the Royal Greenwich Observatory fit the epoch and period in Table 2 very well and do not suggest any change in period, although the observations were too few to permit a new orbital solution.

55 UMa is a very close binary and it is reasonable to expect that both components are tidally distorted. Abt & Levy (1976) have shown that light variations ($\Delta U \sim 0.03$ mag) in HR 976 are due to the ellipsoidal nature of the components. HR 976 probably contains a total mass of $\sim 3.5 M_\odot$ and has a period of 5.5 day. 55 UMa is more massive and the stars are closer; thus it may show larger photometric variations than HR 976, depending on the inclination. Assuming a total mass of $4 M_\odot$ for the system, reasonable for two mid to late A stars (Allen 1973), an inclination ~ 35° is derived. Any variations would therefore be about half the maximum variation visible in the plane of the orbit, but are probably observable. The inclination is too small for eclipses to be observed. Adopting a radius of $\sim 1.5 R_\odot$ for the components, a synchronous rotational velocity of $\sim 30\,\mathrm{km\,s^{-1}}$ is expected. The observed $V_\mathrm{e} \sin i$ of the sharper component is $\sim 35\,\mathrm{km\,s^{-1}}$ giving $V_\mathrm{e} \sim 60\,\mathrm{km\,s^{-1}}$, assuming the axis of rotation is normal to the orbital plane. It is clearly not in synchronous rotation but may be rotating at twice the synchronous velocity. An alternative possibility is that the rotational velocity has become synchronized at periastron where tidal effects are strongest and this will produce a rotational velocity higher than a simple synchronized velocity. The rotational velocity of the broad component is more difficult to measure but is probably $V_\mathrm{e} \sim 140\,\mathrm{km\,s^{-1}}$. It would be worth investigating other eccentric, short-period systems to determine whether or not lack of synchronism were a common feature.

8 Conclusions

55 UMa is an unusual system with a short period and high eccentricity. It contains two similar main sequence stars with spectral types in the range A5 to A9. Broadband photometry suggests that it has a slight ultraviolet excess over similar main-sequence stars. The rotational velocities of the two components are approximately 2 and 5 times the expected synchronous velocity and, among short-period binaries this degree of departure from synchronism is extreme. The faster rotator is probably the more massive star. Various effects may be

expected as a result of tidal distortion and rapid rotation of the two components. The advance of the line of apsides, while not detected here, is likely and might be detected with new observations and orbital solution. Line blending and dilution are such that very good signal to noise would be required. Finally, distortion of the components may lead to ellipsoidal variations of perhaps 0.02 mag.

Acknowledgments

It is a pleasure to thank Dr A. H. Batten for permission to use the vast amount of plate material amassed at Victoria. Special thanks are also due to Paul Murdin, David Stickland, Norman Walker and David Pike for many stimulating discussions and to Brian Emerson for the use of the orbital elements programs.

References

Abt, H. A. & Levy, S. G., 1976. *Publs astr. Soc. Pacif.*, **88**, 487.

Allen, C. W., 1973. *Astrophysical Quantities*, third edn, Athlone Press, London.

Baschek, B. & Searle, L., 1969. *Astrophys. J.*, **155**, 537.

Batten, A. H., Fletcher, J. M. & Mann, P. J. 1978. *Publs Dom. Astrophys. Obs.*, **15**, 121.

Conti, P. S., 1970. *Publs astr. Soc. Pacif.*, **82**, 781.

Cristaldi, S., 1970. *Astr. J.*, **5**, 228.

Eggen, O. J., 1963. *Astr. J.*, **68**, 697.

Gray, D. F. & Desikachary, K. A., 1973. *Astrophys. J.*, **181**, 523.

Henroteau, F., 1919. *Popular Astr.*, **27**, 29.

Hulse, R. A. & Taylor, J. H., 1975. *Astrophys. J.*, **195**, L51.

Iriarte, B., Johnson, H. L., Mitchell, R. I. & Wisniewski, W. K., 1965. *Sky. Telesc.*, **30**, 21.

Jenkins, L. F., 1952. *General Catalogue of Trigonometric Stellar Parallaxes*, Yale University Observatory.

Johnson, H. L., 1966. *A. Rev. Astr. Astrophys.*, **4**, 193.

Kraft, R. P., 1962. *Astrophys. J.*, **135**, 408.

Kraft, R. P., 1964. *Astrophys. J.*, **139**, 457.

Mallama, A. D., 1978. *Acta astr.*, **28**, 31.

Osawa, K., 1959. *Astrophys. J.*, **130**, 159.

Petrie, R. M., Andrews, D. H. & Scarfe, C. D., 1967. *IAU Symp. No. 30*, p. 221, ed. Batten, A.H. & Heard, J.F.

Plavec, M., 1970. *Stellar Rotation, IAU Coll. No. 4*, p. 133, ed. Slettabak, A.

Press, W. H., Wiita, P. J. & Smarr, L. L., 1975. *Astrophys. J.*, **202**, L135.

Sargent, W. L. W., 1965. *Astrophys. J.*, **142**, 787.

Tatum, J. B., 1968. *Mon. Not. R. astr. Soc.*, **141**, 43.

Wheeler, J. C., McKee, C. F. & Lecar, M., 1974. *Astrophys. J.*, **192**, L71.